Attachment A

OEM Data on Refrigerant Distribution in AC System Components
(Example 1)
Refrigerant Distribution Analysis

Updated Jun 25, 2013
Refrigerant Distribution for Three Configurations

<table>
<thead>
<tr>
<th>Component Description</th>
<th>Refrigerant Distribution HEV Sedan</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>System Off (10°C)</td>
</tr>
<tr>
<td>Discharge Line</td>
<td>11%</td>
</tr>
<tr>
<td>Condenser/Receiver</td>
<td>47%</td>
</tr>
<tr>
<td>Liquid Line</td>
<td>6%</td>
</tr>
<tr>
<td>Evaporator</td>
<td>3%</td>
</tr>
<tr>
<td>Suction Line</td>
<td>31%</td>
</tr>
<tr>
<td>Compressor</td>
<td>2%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
</tr>
</tbody>
</table>

- System On data from A/C Simulation software and bench data
- System off data assumes Evaporator ambient is 12°C and is the refrigerant is superheated
  - All other components/lines are saturated at 10°C ambient

<table>
<thead>
<tr>
<th>Component Description</th>
<th>Refrigerant Distribution Van Front Only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>System Off (10°C)</td>
</tr>
<tr>
<td>Discharge Line</td>
<td>12%</td>
</tr>
<tr>
<td>Condenser/Receiver</td>
<td>39%</td>
</tr>
<tr>
<td>Liquid Line (Main)</td>
<td>4%</td>
</tr>
<tr>
<td>Evaporator (Main)</td>
<td>5%</td>
</tr>
<tr>
<td>Suction Line (Main)</td>
<td>29%</td>
</tr>
<tr>
<td>Compressor</td>
<td>11%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Component Description</th>
<th>Refrigerant Distribution Van Front &amp; Aux</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>System Off (10°C)</td>
</tr>
<tr>
<td>Discharge Line</td>
<td>7%</td>
</tr>
<tr>
<td>Condenser/Receiver</td>
<td>22%</td>
</tr>
<tr>
<td>Liquid Line (Main)</td>
<td>2%</td>
</tr>
<tr>
<td>Liquid Line (Aux)</td>
<td>8%</td>
</tr>
<tr>
<td>Evaporator (Main)</td>
<td>2%</td>
</tr>
<tr>
<td>Evaporator (Aux)</td>
<td>2%</td>
</tr>
<tr>
<td>Suction Line (Main)</td>
<td>16%</td>
</tr>
<tr>
<td>Suction Line (Aux)</td>
<td>33%</td>
</tr>
<tr>
<td>Compressor</td>
<td>6%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
</tr>
</tbody>
</table>
Attachment B

OEM Data on Refrigerant Distribution in AC System Components
(Example 2)
Refrigerant distribution per component:
Oil Distribution per component:

- **Compressor / Suction line**
- **Condenser / Discharge line**
- **Evaporator / TXV**
- **AC liquid line**

Oil amount in grams - single evaporator system

- **High Amb**
- **Mid Amb**
Refrigerant Distribution and Oil Distribution in percentage per Component: High and medium ambient condition summary

<table>
<thead>
<tr>
<th>Refrigerant and Compressor Oil Distribution Single evaporator system</th>
<th>Oil Distribution (%)</th>
<th>Refrigerant Distribution (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressor / Suction line</td>
<td>44.1</td>
<td>2.2</td>
</tr>
<tr>
<td>Condenser / Discharge line</td>
<td>33.8</td>
<td>77.5</td>
</tr>
<tr>
<td>Evaporator / TXV</td>
<td>21.4</td>
<td>9.0</td>
</tr>
<tr>
<td>AC liquid line</td>
<td>0.7</td>
<td>11.4</td>
</tr>
<tr>
<td><strong>TOTAL:</strong></td>
<td><strong>100.0</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Refrigerant and Compressor Oil Distribution Single evaporator system</th>
<th>Oil Distribution (%)</th>
<th>Refrigerant Distribution (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressor / Suction line</td>
<td>41.8</td>
<td>3.1</td>
</tr>
<tr>
<td>Condenser / Discharge line</td>
<td>40.3</td>
<td>69.4</td>
</tr>
<tr>
<td>Evaporator / TXV</td>
<td>17.2</td>
<td>14.5</td>
</tr>
<tr>
<td>AC liquid line</td>
<td>0.7</td>
<td>13.0</td>
</tr>
<tr>
<td><strong>TOTAL:</strong></td>
<td><strong>100.0</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>
Attachment C

OEM Data on the Impact of Steam Release During Collision on Refrigerant Ignition and Fire Propagation (Example 1)
Coolant Behavior Consideration
Problem Definition

**Question:**
What impact does the release of coolant have on the mitigation of refrigerant ignitions?

**Hypothesis:**
Releasing coolant will generate vapor aerosolized water particles (steam) that will displace oxygen, replacing it with a non-combustible material. The presence of steam would therefore tend to quench ignition and any propagation that may occur.

**Methodology:**
1) Summarize theory of coolant release relating to oxygen
2) Rate of occurrence of radiator breach through CAE & crashed vehicles
3) Impact of steam during actual vehicle testing
4) Relevance of timing: steam generation vs presence of refrigerant
5) Conclusions
Theory of Coolant Release
Coolant Release Impact

• When a radiator breaches, coolant is released under hood. This calculation is performed at equilibrium vapor conditions and ideal gas assumptions. Does not consider aerosol effect.

• Plot shows
  • R-1234yf @ 7.75 vol-% (stoich.)
  • Dry air (79 vol-% N₂ & 21 vol-% O₂)
    With a radiator breach containing
  • 50:50 mix C₂H₆O₂ and H₂O

• Key Facts/Observations
  • 15 vol-% O₂ needed for ignition
    • US Bureau of Mines Bulletin 627
  • O₂ < 15% occurs when coolant 70°C – 80°C
  • Coolant temperature always > 80°C when exhaust surface > 700°C
  • This analysis very conservative
    • Not consider heat capacity of water vapor and aerosol
    • Does not consider displacement of refrigerant by steam
      • Heat sink to pull heat from ignition kernel of weak flame

Calculations suggest ignitions mitigated whenever coolant breach occurs
Rate of Occurrence of Coolant Breach
- CAE and Crashed Vehicles -
Radiator Breach Behavior

**Question:**
Coolant expected to have significant mitigating impact, but how often radiator breach occur during collision?

**CAE Analysis – front-end collision**

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Component</th>
<th>Speed (kph)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>Vehicle #1</td>
<td>Condenser</td>
<td>n/a</td>
</tr>
<tr>
<td>Vehicle #1</td>
<td>Radiator</td>
<td>n/a</td>
</tr>
<tr>
<td>Vehicle #2</td>
<td>Condenser</td>
<td></td>
</tr>
<tr>
<td>Vehicle #2</td>
<td>Radiator</td>
<td></td>
</tr>
<tr>
<td>Vehicle #3</td>
<td>Condenser</td>
<td></td>
</tr>
<tr>
<td>Vehicle #3</td>
<td>Radiator</td>
<td></td>
</tr>
</tbody>
</table>

CAE analysis indicates that radiator will always breach
- at lower speeds than that required to breach the A/C system or
- during a collision severe enough to breach A/C system
Radiator Breach Behavior (2)

**Question:**
Coolant expected to have significant mitigating impact, but how often radiator breach occur during collision?

**Vehicle Data—front-end collision**

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Speed (kph)</th>
<th>Radiator</th>
<th>Condenser</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle #1</td>
<td>56</td>
<td>Breach</td>
<td>Breach</td>
</tr>
<tr>
<td>Vehicle #2</td>
<td>42.5</td>
<td>Breach</td>
<td>Breach</td>
</tr>
<tr>
<td>Vehicle #3</td>
<td>45</td>
<td>Breach</td>
<td>No Breach</td>
</tr>
<tr>
<td></td>
<td>45</td>
<td>Breach</td>
<td></td>
</tr>
<tr>
<td></td>
<td>45</td>
<td>Breach</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>Breach</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>Breach</td>
<td></td>
</tr>
</tbody>
</table>

Vehicle data from actual crash tests validate CAE analysis → radiator always breached
- at lower speeds than that required to breach the A/C system or
- during a collision severe enough to breach A/C system
Impact of steam during actual vehicle testing
Steam Impact – Release Testing

Test Setup:
- Daimler nozzle, fully tuned system for ignition, > 790°C surface temps, fan off

<table>
<thead>
<tr>
<th>Configuration</th>
<th># tests</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>No coolant release</td>
<td>5</td>
<td>Ignition (5/5)</td>
</tr>
<tr>
<td>Coolant Release</td>
<td>5</td>
<td>No Ignitions (0/5)</td>
</tr>
</tbody>
</table>

Sample of release test showing steam impact:

Coolant release always mitigated ignition of refrigerant
Steam Impact – full hot/wet crash tests

Test Setup:
- Production level vehicle, all fluids, 750 - 790°C surface temps, 45kph - 50kph

Sample of release test showing steam impact:

Coolant release always occurred. Refrigerant ignition never occurred
Relevance of Timing
- steam generation vs presence of refrigerant -
Timing of Steam Generation vs Refrigerant Release

**Question:**
Calculations may show that coolant has a mitigating effect, but do the 2 occur at the same time and in the same location?

**Evidence:**

Refrigerant often leaks out < 60sec

Steam generated for minutes

This picture is 125 sec after collision (continues for many more minutes)

Steam generated in same location and for longer time than refrigerant concentration
Conclusions

- Coolant release significantly mitigate refrigerant ignitions
  - Calculations show $O_2$ levels not high enough to support ignition
  - CAE simulations indicate radiator will always breach
    - At lower speeds than A/C system breach occur or
    - During collision severe enough to damage A/C system
  - Real crash data validate CAE simulations
  - Release tests demonstrated coolant always mitigate refrigerant ignition
  - Crash testing showed
    - Coolant always released during testing
    - No ignitions observed
Attachment D

OEM Data on the Impact of Steam Release During Collision on Refrigerant Ignition and Fire Propagation (Example 2)
**Executive Summary**

<table>
<thead>
<tr>
<th>Purpose</th>
<th>1) Conduct Crash tests with production fluids in order to better understand input parameters and probabilities for the CRP1234-4 Risk Assessment</th>
</tr>
</thead>
</table>
| Scope | 1) Conduct Crash Tests on a C & D Segment Size Vehicle  
a) Crash Test Type is a 64kph Right Hand 40% Offset Rigid Barrier  
b) Engine RPM set to Maximum in order to achieve high exhaust temps with Air Conditioning On  
c) All vehicle fluids filled to standard production levels, which includes R-1234yf & PAG Oil for the Air Conditioning System |
| Analysis | 1) Both C & D Segment vehicle crash tests resulted in no Refrigerant Ignition  
a) The maximum exhaust manifold surface temperature at impact was approximately 542 C  
b) All A/C components (Compressor, Condenser and A/C Lines) were all broken  
c) Considerable amount of steam was observed for more than 60 seconds after impact  
  i. Even if the exhaust surface temps were above 800C this would allow enough time for surface temps to drop below the refrigerant ignition temperature of 700 C, which is the conservative value that is used for the CRP1234-4 Risk Assessment  
  1. Exhaust Surface temps typically cool at a rate of 3 to 5 C per second at these extreme temperatures |
| Conclusion | 1) These tests indicate that Coolant should be considered as a mitigating factor in the Fault Tree Analysis Risk assessment due to the considerable amount of steam observed after impact. |
Crash Test Information

1) Pre-condition
   a) Ambient temperature: 15 ~ 20°C
   b) Engine RPM set to Maximum in order to achieve high exhaust temps with Air Conditioning On
   c) All vehicle fluids filled to standard production levels, which includes R-1234yf & PAG Oil for the Air Conditioning System

<table>
<thead>
<tr>
<th>Items</th>
<th>C SEG Passenger</th>
<th>D SEG SUV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine</td>
<td>Gasoline I4 1.6L</td>
<td>Gasoline V6 3.3L</td>
</tr>
<tr>
<td>Exhaust manifold position</td>
<td>Rear side of eng. room</td>
<td>Front/rear side of eng. room</td>
</tr>
<tr>
<td>Exhaust gas temperature(°C)</td>
<td></td>
<td>760</td>
</tr>
<tr>
<td>Exhaust manifold surface temperature(°C)</td>
<td>495~542</td>
<td>520</td>
</tr>
<tr>
<td>Engine room air temperature (°C)</td>
<td>80~100</td>
<td>105</td>
</tr>
<tr>
<td>Coolant temperature(°C)</td>
<td>102</td>
<td>117</td>
</tr>
<tr>
<td>Engine oil temperature(°C)</td>
<td>136</td>
<td>144</td>
</tr>
<tr>
<td>High pressure(psi)</td>
<td>207</td>
<td>218</td>
</tr>
<tr>
<td>Low pressure(psi)</td>
<td></td>
<td>23</td>
</tr>
<tr>
<td>High pressure side temp.(°C)</td>
<td>97</td>
<td>114~130</td>
</tr>
<tr>
<td>Low pressure side temp.(°C)</td>
<td>15</td>
<td>29</td>
</tr>
</tbody>
</table>

2) Crash Test Type
   a) 64kph Right Hand 40% Offset Rigid Barrier

3) Test Results

<table>
<thead>
<tr>
<th>Items</th>
<th>C SEG Passenger</th>
<th>D SEG SUV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Result</td>
<td>NO ignite</td>
<td>NO ignite</td>
</tr>
<tr>
<td>A/C components</td>
<td>Compressor</td>
<td>Broken</td>
</tr>
<tr>
<td></td>
<td>Condenser</td>
<td>Broken</td>
</tr>
<tr>
<td></td>
<td>A/C plumbing</td>
<td>Broken</td>
</tr>
<tr>
<td></td>
<td>Compressor</td>
<td>Broken</td>
</tr>
<tr>
<td></td>
<td>Condenser</td>
<td>Broken</td>
</tr>
<tr>
<td></td>
<td>A/C plumbing</td>
<td>Broken</td>
</tr>
</tbody>
</table>
## Details

### Vehicle Layout

<table>
<thead>
<tr>
<th>Items</th>
<th>C SEG Passenger</th>
<th>D SEG SUV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layout</td>
<td>LHD</td>
<td>LHD</td>
</tr>
<tr>
<td></td>
<td><img src="image1.png" alt="Diagram C SEG Passenger" /></td>
<td><img src="image2.png" alt="Diagram D SEG SUV" /></td>
</tr>
</tbody>
</table>

- **Engine**
- **T/M**
- **Comp**
- **Cond**

- **Ex-mani**

LHD: Left Hand Drive

---

3
Attachment E

OEM Test Data on Effect of Surface Temperature on Refrigerant Ignition (Example 1)
All data supports use of 700°C as minimum relevant temperature.
No data supports use of auto-ignition temperature (405°C) as being relevant.
## Detailed Test Data (Lab Testing)

### R-134a

<table>
<thead>
<tr>
<th>Figure Legend</th>
<th>Configuration</th>
<th>Ignition Temperature</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>R-134a + PAG oil</td>
<td>&gt; 800°C (no ignition observed)</td>
<td><em>Ignition of refrigerant oil mixtures on hot Surfaces – Ineris</em>(Jan 15, 2009) – CRP1234</td>
</tr>
<tr>
<td>C</td>
<td>R-134a + PAG oil</td>
<td>≥ 837°C (ignition observed due to combustion of PAG oil)</td>
<td><em>Hot Surface Ignition and Fire Propagation Characteristics of R134a and R1234yf Refrigerants – Ford SAE2012-01-0984</em></td>
</tr>
</tbody>
</table>

### R-1234yf

<table>
<thead>
<tr>
<th>Figure Legend</th>
<th>Configuration</th>
<th>Ignition Temperature</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>R-1234yf + PAG oil</td>
<td>≥ 750°C (ignition observed)</td>
<td><em>Ignition of refrigerant oil mixtures on hot Surfaces – Ineris</em>(Jan 15, 2009) – CRP1234</td>
</tr>
<tr>
<td>E</td>
<td>R-1234yf + PAG oil</td>
<td>≥ 700°C (ignition observed but was a short flash lasting 1-2 seconds)</td>
<td><em>Refrigerant Decomposition Tests Part II: Passenger Car Engine Compartment Tests – Hughes</em> (Aug 24, 2009)</td>
</tr>
<tr>
<td>F</td>
<td>R-1234yf + PAG oil</td>
<td>≥ 710°C (ignition observed)</td>
<td><em>Ignition sensitivity and toxics generation by a refrigerant when submitted to a high temperature – Ineris</em> (Nov 26, 2011) – MRB CRP</td>
</tr>
<tr>
<td>G</td>
<td>Pure R-1234yf</td>
<td>≥ 860°C (ignition observed)</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>R-1234yf + PAG oil</td>
<td>≥ 845°C (ignition observed due to combustion of PAG and refrigerant)</td>
<td><em>Hot Surface Ignition and Fire Propagation Characteristics of R134a and R1234yf Refrigerants – Ford SAE2012-01-0984</em></td>
</tr>
</tbody>
</table>
**Detailed Test Data (Vehicle Testing)**

R-1234yf (each row represents the results of multiple tests using a given vehicle)

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Ignition Temperature</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle #1</td>
<td>No ignition observed (vehicle not capable of exceeding 700°C)</td>
<td>OEM Testing (front takedown, gasoline non-turbo)</td>
</tr>
<tr>
<td>Vehicle #2</td>
<td>No ignition observed (includes max exhaust surface temperature 810°C)</td>
<td>OEM Testing (front takedown, gasoline turbo)</td>
</tr>
<tr>
<td>Vehicle #3</td>
<td>≥ 700°C</td>
<td>OEM Testing (longitudinal, gasoline turbo)</td>
</tr>
<tr>
<td>Vehicle #4</td>
<td>≥ 695°C</td>
<td>OEM Testing (front takedown, gasoline turbo)</td>
</tr>
<tr>
<td>Vehicle #5</td>
<td>No ignition observed (includes max surface temperature 775°C)</td>
<td>OEM Testing (rear takedown, gasoline non-turbo)</td>
</tr>
</tbody>
</table>
Attachment F

OEM Test Data on Effect of Surface Temperature on Refrigerant Ignition (Example 2)
Our purpose is to clarify the conditions of refrigerant ignition.
Validation Method

Refrigerant supply vehicles
Controlling of Pd/Ps/OCR

Ignition test vehicle
Controlling of Temp/Space/Release position

※Pd/Ps/OCR detail is shown in list

Releasing Ref & Oil mix gas from exact A/C line of CBU.

Electric heater
### Flammability Test Results

<table>
<thead>
<tr>
<th>CAT Temperature</th>
<th>CAT cover</th>
<th>Bonnet</th>
<th>Under cover</th>
<th>Cooling Fan</th>
<th>Injecting position</th>
<th>Injecting Height</th>
<th>Injection pressure</th>
<th>OCR</th>
<th>Result</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>650</td>
<td>No</td>
<td>Close</td>
<td>Yes</td>
<td>OFF</td>
<td>High side (60mm)</td>
<td>Low</td>
<td>1.5MPaG</td>
<td>3.5%</td>
<td>No ignition</td>
<td>No Propagation</td>
</tr>
<tr>
<td>700</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>No ignition</td>
<td>No Propagation</td>
</tr>
<tr>
<td>760</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>No ignition</td>
<td>No Propagation</td>
</tr>
<tr>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>1.0MPaG</td>
<td>No ignition</td>
</tr>
<tr>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>0.5MPaG</td>
<td>↑</td>
<td>No ignition</td>
<td>No Propagation</td>
</tr>
<tr>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>High</td>
<td>1.0MPaG</td>
<td>Oil ignition</td>
<td>No Propagation</td>
</tr>
<tr>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>0.5MPaG</td>
<td>Oil ignition?</td>
<td>No Propagation</td>
</tr>
<tr>
<td>↑</td>
<td>↑</td>
<td>OPEN</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>1.0MPaG</td>
<td>No ignition</td>
<td>No Propagation</td>
</tr>
<tr>
<td>↑</td>
<td>↑</td>
<td>OPEN</td>
<td>No</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>No ignition</td>
<td>No Propagation</td>
</tr>
<tr>
<td>↑</td>
<td>↑</td>
<td>Close</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>Oil ignition</td>
<td>No Propagation</td>
</tr>
<tr>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>0.5MPaG</td>
<td>Oil ignition</td>
<td>No Propagation</td>
</tr>
</tbody>
</table>

We found some oil ignition phenomenon, but could not find refrigerant ignition condition.
Comparison of Daimler and Realistic Case

<Oil change>
We verified PAG and POE both oil.

<The difference in heat shield structure>

- Realistic -

Structure where a refrigerant stagnates easily

Extension
A heat shield is modified to make a condition close to Daimler.

<Nozzle Structure>

Daimler Nozzle
Daimler Nozzle

Realistic Nozzle

We validated Daimler and realistic both nozzle.
## Test Condition

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Temp</th>
<th>Oil OCR=3.5%</th>
<th>Nozzle</th>
<th>Heat shield</th>
<th>Pd</th>
<th>Fan</th>
<th>Hood</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$\geq 800^\circ$C</td>
<td>PAG</td>
<td>Straight</td>
<td>Mass production *with slit</td>
<td>2.0MPa(gage)</td>
<td>OFF</td>
<td>Close</td>
</tr>
<tr>
<td>2</td>
<td>↑</td>
<td>↑</td>
<td>Daimler</td>
<td>Mass production +without slit +Extension</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>3</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>Without Heat shield</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>4</td>
<td>↑</td>
<td>POE</td>
<td>↑</td>
<td>Mass production +without slit +Extension</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
</tr>
</tbody>
</table>
Validation Result

Temp (℃)

850°C : Equipment maximum temperature

Tested 800°C max

850
800
760
700
650
600
550
500
450
400

Ignition
Spark (No ignition)
PAG OIL
POE OIL

Oil only
(Without 1234yf)

No.1
No.2
No.3
No.4

No ignition Area

With 1234yf
Attachment G

OEM Data from Vehicle Thermal Testing (Example 1)
Thermal Analysis of Exhaust Surfaces
- Methods and Results -
Introduction

Background:
• The CRP team has had numerous discussions to establish conservative inputs into the fault trees
• One of the significant inputs to the trees is the % of time that an average customer will spend above a relevant exhaust surface temperature (i.e. 700°C)
• To date, numerous estimates have been put forward by members of the team but questions remain regarding the right method.

Purpose:
• Provide clarification on a method for determining % of time at temperature > 700°C.
• Substantiate the values currently included in the fault tree

Method
• Identify relevant conditions where temperatures can exceed 700°C using thermal validation procedure
• Relevant Conditions identified as grades, WOT, Vmax
• Analyze real customer data for 4 cyl, V6, V8 to understand drive behavior
  • Data collected from total of 57 vehicles and > 1,270,650 miles
  • 2 regions used: United States and Germany/Europe
• Weibull results and determine % time average customer spend at grade, WOT, Vmax
• Sum % for each to obtain overall % > 700°C
Example of European Study

Due to grade operation
- Average Customer (50%) = 0.06% of time > 700°C
- Severe Customer (90%) = 0.35% of time > 700°C

Due to WOT operation
- Average Customer (50%) = 0.03% of time > 700°C
- Severe Customer (90%) = 0.40% of time > 700°C

Due to Vmax operation
- Average Customer (50%) = 0.03% of time > 700°C
- Severe Customer (90%) = 0.78% of time > 700°C

Aggregate Time > 700°C: US + Europe
- Average Customer (50%) = 0.06% + 0.03% + 0.03% = 0.12% > 700°C
- Severe Customer (90%) = 0.35% + 0.40% + 0.78% = 1.53% > 700°C
Comments on Assessment Method:

This assessment was deemed to be conservative for the following reasons:

- Assumed every vehicle can achieve exhaust surface > 700°C
  - Not reduce occurrence % for diesel or NA vehicles
- Assumed a WOT of any duration resulted in temp > 700°C
  - Profile data suggests multiple back-to-back WOTs necessary
- Assumed top 3 speed bands same as Vmax resulting in temp > 700°C
- Assumed Vmax is relevant for all regions of globe – no reduction in occurrence %
  - Data suggests not a relevant consideration for US
- Assumed that continuous driving at grade > 4% for 90s results in temp > 700°C
- Adding across 90% bands for grade, WOT, Vmax overinflates 90% result
  - Likely reporting 99% result
Backup
Grade Consideration:

Grades:
- Analyzed grade profile data from thermal testing and found that the user needs to operate continuously at a grade to exceed 700°C
  - The relevant continuous time was determined to be 90 seconds
- Sorting condition used was
  - Measured grade > X% (used 4%, 7%, 12%)
  - Vehicle speed > 0kph
  - Continuous time > 90 seconds
- Number of occurrences determined, Weibull results
- Select average (50%) customer and a severe (90%) customer to determine time at grade

Conservative Assumptions:
- Any time that grade > X% for continuous 90s (speed > 0kph) → assume exhaust surface > 700°C
- All vehicles can achieve 700°C → no consideration for diesels or NA vehicles that cannot reach 700°C
**WOT Consideration:**

**Wide Open Throttle (WOT):**
- Analyzed thermal profile data from thermal testing and found that the user needs to operate back-to-back WOTs to exceed 700°C
  - Determined that need to be > 10s long within 20s of each other
- Initial Result
  - Analyzed 24 vehicles (309,601 miles) and did not find 1 occurrence of this
- Modified Criteria
  - Considered that whenever WOT occurs, temperature > 700°C

**Conservative Assumptions:**
- Any time that WOT occurs, even momentary, assumed that temp > 700°C
  - Data suggests that continuous preconditioning is required
  - Necessary preconditioning never occurred in all vehicles analyzed
- All vehicles can achieve 700°C → no consideration for diesels or NA vehicles that cannot reach 700°C
Vmax Consideration:

Vmax:
• Analyzed thermal profile data from thermal testing and found that the user needs to operate continuously at Vmax to exceed 700°C
  • Determined that need to be > 30s long
• Initial Result
  • Analyzed 33 vehicles (>550,000 miles) in US and did not find Vmax occurrence
  • 24 analyzed (706,000 miles) 4 cyl in Germany
• Modified Criteria
  • Considered that whenever Vmax occurs, for any period, temperature > 700°C
  • Considered speeds in 2 bands below Vmax as > 700°C

Conservative Assumptions:
• Any time that Vmax occurs, even momentary, assumed that temp > 700°C
  • Data suggests that continuous preconditioning is required
• All vehicles can achieve 700°C → no consideration for diesels or NA vehicles that cannot reach 700°C
• Expanded to lower speed bands and included as “Vmax”
Attachment H

OEM Data from Vehicle Thermal Testing (Example 2)
Thermal Testing Summary

June 20, 2013
Thermal Testing Summary

- **Vehicle:** Small CUV
  - 2.0L Turbocharged Direct Injection Gas Engine
  - Automatic Transmission

- **Testing Location:**
  - Location was Southwestern USA (north of Phoenix, AZ)
  - Two circular routes West and East of I-17
  - Conducted in both clockwise & counterclockwise directions
  - Location was selected based on worst case routes in Arizona for grades and loads on vehicle
  - Location was not selected for highest possible ambient
Thermal Testing Summary

• Testing Methodology:
  – Testing objective was to produce highest possible underhood exhaust temperatures
  – Highest temperatures are not seen under more modest loads or more normal driving profiles
  – Vehicle had to be driven at or near load limits to produce highest temperatures
  – “Base” testing w/o a trailer was at near max vehicle load (98% GVWR)
  – “Trailer” testing was at max rating for vehicle plus trailer; combined weight rating (100% GCWR),
Chart Title Key: Base or Trailer_West or East_CW or CCW direction_Date yyyymmdd
Chart Title Key: Base or Trailer_West or East_CW or CCW direction_Date yyyymmdd

Route
Ambient 27 - 42°C

- Temp >700°C 5.69% of Time
- Longest time=0:01:43
- Max Temp 753 °C
Route
Ambient 22 - 38°C

Temp >700°C 15.69% of Time
Longest time=0:03:02
Max Temp 773 °C
## Thermal Testing Summary of Results

<table>
<thead>
<tr>
<th>Route</th>
<th>Direction</th>
<th>Test Condition (Base or Trailer)</th>
<th>Percent Time &gt;700°C</th>
<th>Longest Time &gt;700°C (h:mm:ss)</th>
<th>Maximum (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>West</td>
<td>CW</td>
<td>Base</td>
<td>0.8%</td>
<td>0:01:17</td>
<td>734</td>
</tr>
<tr>
<td>West</td>
<td>CCW</td>
<td>Base</td>
<td>0.3%</td>
<td>0:00:16</td>
<td>713</td>
</tr>
<tr>
<td>East</td>
<td>CW</td>
<td>Base</td>
<td>1.6%</td>
<td>0:01:41</td>
<td>738</td>
</tr>
<tr>
<td>East</td>
<td>CCW</td>
<td>Base</td>
<td>0.9%</td>
<td>0:01:04</td>
<td>724</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Average</td>
<td>0.9%</td>
<td>0:01:04</td>
<td>727</td>
</tr>
<tr>
<td>West</td>
<td>CW</td>
<td>Trailer</td>
<td>8.8%</td>
<td>0:03:24</td>
<td>772</td>
</tr>
<tr>
<td>West</td>
<td>CCW</td>
<td>Trailer</td>
<td>5.7%</td>
<td>0:01:43</td>
<td>753</td>
</tr>
<tr>
<td>East</td>
<td>CW</td>
<td>Trailer</td>
<td>11.9%</td>
<td>0:03:34</td>
<td>775</td>
</tr>
<tr>
<td>East</td>
<td>CCW</td>
<td>Trailer</td>
<td>15.7%</td>
<td>0:03:02</td>
<td>773</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Average</td>
<td>10.5%</td>
<td>0:02:56</td>
<td>768</td>
</tr>
<tr>
<td>Average Adjusted for Customer Usage</td>
<td>Trailer</td>
<td>&lt;0.1%</td>
<td>0:02:56</td>
<td>768</td>
<td></td>
</tr>
</tbody>
</table>

* Customer Trailer Usage is less the 1% of total operating hours

Considering the severity of the routes and the amount of time customers tow trailers, use of 1% for time greater than 700°C in the SAE CRP FTA is reasonable.
Attachment I

Analysis of GIDAS Database Regarding Fires and Fuel Releases
FUEL LEAKAGE & CARS CAUGHT FIRE AFTER FRONTAL/SIDE IMPACT IN GIDAS*

April 2013

* GIDAS: German In-Depth Accidents Study

⇒ current status July 2012 (22,347 Accidents)
## Fuel Leakage of cars after frontal impact in GIDAS

### Case Selection:
- 1st collision
- only cars
- frontal impacts (PDOF=11,12,1)
- EES<>"unknown"

### Year of 1st Registration & EES

<table>
<thead>
<tr>
<th>Year of 1st Reg.</th>
<th>EES</th>
<th>No / Unknown</th>
<th>Yes</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td>&lt;2000</td>
<td>7245</td>
<td>60,6%</td>
<td>400</td>
<td>5,5%</td>
</tr>
<tr>
<td>2000+</td>
<td>3655</td>
<td>30,6%</td>
<td>102</td>
<td>2,8%</td>
</tr>
<tr>
<td>Unknown</td>
<td>1063</td>
<td>8,9%</td>
<td>61</td>
<td>5,7%</td>
</tr>
<tr>
<td>Total</td>
<td>11963</td>
<td>100%</td>
<td>563</td>
<td>4,7%</td>
</tr>
</tbody>
</table>

---

### Year of 1st Registration & EES

<table>
<thead>
<tr>
<th>Year of 1st Reg.</th>
<th>EES</th>
<th>Fuel Leakage (FL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td>&lt; 16 Km/h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;2000</td>
<td>3696</td>
<td>98,1%</td>
</tr>
<tr>
<td>2000+</td>
<td>1381</td>
<td>95,5%</td>
</tr>
<tr>
<td>Unknown</td>
<td>49</td>
<td>77,8%</td>
</tr>
<tr>
<td>Total</td>
<td>3553</td>
<td>97,2%</td>
</tr>
</tbody>
</table>

---

### Year of 1st Registration & EES

<table>
<thead>
<tr>
<th>Year of 1st Reg.</th>
<th>EES</th>
<th>Fuel Leakage (FL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td>16-50 Km/h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;2000</td>
<td>3047</td>
<td>92,0%</td>
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<tr>
<td>2000+</td>
<td>102</td>
<td>62,6%</td>
</tr>
<tr>
<td>Unknown</td>
<td>102</td>
<td>61</td>
</tr>
<tr>
<td>Total</td>
<td>6845</td>
<td>94,5%</td>
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</table>

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### Year of 1st Registration & EES

<table>
<thead>
<tr>
<th>Year of 1st Reg.</th>
<th>EES</th>
<th>Fuel Leakage (FL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
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<tr>
<td>&gt; 50 Km/h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;2000</td>
<td>102</td>
<td>62,6%</td>
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<tr>
<td>2000+</td>
<td>102</td>
<td>37,4%</td>
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<tr>
<td>Unknown</td>
<td>102</td>
<td>61</td>
</tr>
<tr>
<td>Total</td>
<td>102</td>
<td>37,4%</td>
</tr>
</tbody>
</table>

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### Year of 1st Registration & EES

<table>
<thead>
<tr>
<th>Year of 1st Reg.</th>
<th>EES</th>
<th>Fuel Leakage (FL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td>Sub Total of &lt;2000</td>
<td>7245</td>
<td>100%</td>
</tr>
<tr>
<td>Sub Total of 2000+</td>
<td>3655</td>
<td>100%</td>
</tr>
<tr>
<td>Sub Total of &quot;Unknown&quot;</td>
<td>1063</td>
<td>100%</td>
</tr>
<tr>
<td>Total</td>
<td>11963</td>
<td>100%</td>
</tr>
</tbody>
</table>

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### Year of 1st Registration & EES

<table>
<thead>
<tr>
<th>Year of 1st Reg.</th>
<th>EES</th>
<th>Fuel Leakage (FL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td>No / Unknown</td>
<td>7245</td>
<td>60,6%</td>
</tr>
<tr>
<td>Yes</td>
<td>400</td>
<td>5,5%</td>
</tr>
<tr>
<td>All</td>
<td>11963</td>
<td>100%</td>
</tr>
</tbody>
</table>

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### Year of 1st Registration & EES

<table>
<thead>
<tr>
<th>Year of 1st Reg.</th>
<th>EES</th>
<th>Fuel Leakage (FL)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td>No / Unknown</td>
<td>7245</td>
<td>60,6%</td>
</tr>
<tr>
<td>Yes</td>
<td>400</td>
<td>5,5%</td>
</tr>
<tr>
<td>All</td>
<td>11963</td>
<td>100%</td>
</tr>
</tbody>
</table>
## Fuel leakage of cars after side impact in GIDAS

### Case Selection:
- 1\textsuperscript{st} collision
- only cars
- side impacts (PDOF=2,3,4,8,9,10)
- EES<>"unknown"

### Year of 1\textsuperscript{st} Registration & EES

<table>
<thead>
<tr>
<th>Year of 1\textsuperscript{st} Reg.</th>
<th>EES</th>
<th>Fuel Leakage (FL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>% *</td>
</tr>
<tr>
<td>&lt;2000</td>
<td>2870</td>
<td>59,1%</td>
</tr>
<tr>
<td>2000+</td>
<td>1590</td>
<td>32,7%</td>
</tr>
<tr>
<td>Unknown</td>
<td>400</td>
<td>8,2%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>4860</td>
<td>100%</td>
</tr>
</tbody>
</table>

* % per column
** % per row of All

### Year of 1\textsuperscript{st} Registration & EES

<table>
<thead>
<tr>
<th>Year of 1\textsuperscript{st} Reg.</th>
<th>EES</th>
<th>Fuel Leakage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td>&lt;2000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 16 Km/h</td>
<td>1692</td>
<td>98,0%</td>
</tr>
<tr>
<td>16-50 Km/h</td>
<td>1051</td>
<td>94,9%</td>
</tr>
<tr>
<td>&gt; 50 Km/h</td>
<td>19</td>
<td>52,8%</td>
</tr>
<tr>
<td>Sub Total of &lt;2000</td>
<td>2762</td>
<td>96,2%</td>
</tr>
<tr>
<td>2000+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 16 Km/h</td>
<td>1092</td>
<td>99,1%</td>
</tr>
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<td>16-50 Km/h</td>
<td>457</td>
<td>95,6%</td>
</tr>
<tr>
<td>&gt; 50 Km/h</td>
<td>6</td>
<td>60,0%</td>
</tr>
<tr>
<td>Sub Total of 2000+</td>
<td>1555</td>
<td>97,8%</td>
</tr>
<tr>
<td>Unknown</td>
<td></td>
<td></td>
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<td>&lt; 16 Km/h</td>
<td>229</td>
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<tr>
<td>16-50 Km/h</td>
<td>161</td>
<td>100,0%</td>
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<tr>
<td>&gt; 50 Km/h</td>
<td>10</td>
<td>100,0%</td>
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<tr>
<td>Sub Total of &quot;Unknown&quot;</td>
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</tr>
<tr>
<td><strong>Total</strong></td>
<td>4717</td>
<td>97,1%</td>
</tr>
</tbody>
</table>
## Cars caught fire after frontal impact in GIDAS

<table>
<thead>
<tr>
<th>Year of 1st registration</th>
<th>All</th>
<th></th>
<th>Cars caught Fire</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
<td>n</td>
<td>%</td>
<td>**</td>
</tr>
<tr>
<td>&lt;2000</td>
<td>7245</td>
<td>60,6%</td>
<td>60</td>
<td>0,8%</td>
<td></td>
</tr>
<tr>
<td>2000+</td>
<td>3655</td>
<td>30,6%</td>
<td>16</td>
<td>0,4%</td>
<td></td>
</tr>
<tr>
<td>Unknown</td>
<td>1063</td>
<td>8,9%</td>
<td>0</td>
<td>0,0%</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>11963</td>
<td>100%</td>
<td>76</td>
<td>0,6%</td>
<td></td>
</tr>
</tbody>
</table>

* % per column  ** % per row of All

### Case Selection:
- 1st collision
- only cars
- frontal impacts (PDOF=11,12,1)
- EES<>“unknown”

### Year of 1st Registration & EES

<table>
<thead>
<tr>
<th>Year of 1st Reg.</th>
<th>EES</th>
<th>n</th>
<th>%</th>
<th>n</th>
<th>%</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;2000</td>
<td>&lt; 16 Km/h</td>
<td>3753</td>
<td>99,6%</td>
<td>16</td>
<td>0,4%</td>
<td>3769</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>16-50 Km/h</td>
<td>3281</td>
<td>99,0%</td>
<td>32</td>
<td>0,4%</td>
<td>3313</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>&gt; 50 Km/h</td>
<td>151</td>
<td>92,6%</td>
<td>12</td>
<td>0,7%</td>
<td>163</td>
<td>100%</td>
</tr>
<tr>
<td>Sub Total of &lt;2000</td>
<td></td>
<td>7185</td>
<td>99,2%</td>
<td>60</td>
<td>0,8%</td>
<td>7245</td>
<td>100%</td>
</tr>
<tr>
<td>2000+</td>
<td>&lt; 16 Km/h</td>
<td>2142</td>
<td>99,8%</td>
<td>4</td>
<td>0,2%</td>
<td>2146</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>16-50 Km/h</td>
<td>1437</td>
<td>99,4%</td>
<td>9</td>
<td>0,6%</td>
<td>1446</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>&gt; 50 Km/h</td>
<td>60</td>
<td>95,2%</td>
<td>3</td>
<td>4,8%</td>
<td>63</td>
<td>100%</td>
</tr>
<tr>
<td>Sub Total of 2000+</td>
<td></td>
<td>3639</td>
<td>99,6%</td>
<td>16</td>
<td>0,4%</td>
<td>3655</td>
<td>100%</td>
</tr>
<tr>
<td>Unknown</td>
<td>&lt; 16 Km/h</td>
<td>568</td>
<td>100,0%</td>
<td>0</td>
<td>0,0%</td>
<td>568</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>16-50 Km/h</td>
<td>452</td>
<td>100,0%</td>
<td>0</td>
<td>0,0%</td>
<td>452</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>&gt; 50 Km/h</td>
<td>43</td>
<td>100,0%</td>
<td>0</td>
<td>0,0%</td>
<td>43</td>
<td>100%</td>
</tr>
<tr>
<td>Sub Total of &quot;Unknown&quot;</td>
<td></td>
<td>1063</td>
<td>100,0%</td>
<td>0</td>
<td>0,0%</td>
<td>1063</td>
<td>100%</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>11887</td>
<td>99,4%</td>
<td>76</td>
<td>0,6%</td>
<td>11963</td>
<td>100%</td>
</tr>
</tbody>
</table>
**Cars caught fire after side impact in GIDAS**

<table>
<thead>
<tr>
<th>Year of 1(^{st}) registration</th>
<th>All</th>
<th>Cars caught Fire</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td>&lt;2000</td>
<td>2870</td>
<td>59,1%</td>
</tr>
<tr>
<td>2000+</td>
<td>1590</td>
<td>32,7%</td>
</tr>
<tr>
<td>Unknown</td>
<td>400</td>
<td>8,2%</td>
</tr>
<tr>
<td>Total</td>
<td>4860</td>
<td>100%</td>
</tr>
</tbody>
</table>

* % per column
** % per row of All

**Case Selection:**
- 1\(^{st}\) collision
- only cars
- side impacts (PDOF=2,3,4&8,9,10)
- EES<>"unknown"

<table>
<thead>
<tr>
<th>Year of 1(^{st}) Registration &amp; EES</th>
<th>No / Unknown</th>
<th>Cars caught fire</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
<td>n</td>
</tr>
<tr>
<td>&lt;2000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 16 Km/h</td>
<td>1724</td>
<td>99,8%</td>
<td>3</td>
</tr>
<tr>
<td>16-50 Km/h</td>
<td>1099</td>
<td>99,3%</td>
<td>8</td>
</tr>
<tr>
<td>&gt; 50 Km/h</td>
<td>36</td>
<td>100,0%</td>
<td>0</td>
</tr>
<tr>
<td>Sub Total of &lt;2000</td>
<td>2859</td>
<td>99,6%</td>
<td>11</td>
</tr>
<tr>
<td>2000+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 16 Km/h</td>
<td>1102</td>
<td>100,0%</td>
<td>0</td>
</tr>
<tr>
<td>16-50 Km/h</td>
<td>477</td>
<td>99,8%</td>
<td>1</td>
</tr>
<tr>
<td>&gt; 50 Km/h</td>
<td>10</td>
<td>100,0%</td>
<td>0</td>
</tr>
<tr>
<td>Sub Total of 2000+</td>
<td>1589</td>
<td>99,9%</td>
<td>1</td>
</tr>
<tr>
<td>Unknown</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 16 Km/h</td>
<td>229</td>
<td>100,0%</td>
<td>0</td>
</tr>
<tr>
<td>16-50 Km/h</td>
<td>161</td>
<td>100,0%</td>
<td>0</td>
</tr>
<tr>
<td>&gt; 50 Km/h</td>
<td>10</td>
<td>100,0%</td>
<td>0</td>
</tr>
<tr>
<td>Sub Total of &quot;Unknown&quot;</td>
<td>400</td>
<td>100,0%</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>4848</td>
<td>99,8%</td>
<td>12</td>
</tr>
</tbody>
</table>
## Fuel leakage & cars caught fire after frontal impact in GIDAS

<table>
<thead>
<tr>
<th>Year of 1(^{\text{st}}) registration</th>
<th>All</th>
<th>FL + Caught Fire</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td>&lt;2000</td>
<td>7245</td>
<td>60,6%</td>
</tr>
<tr>
<td>2000+</td>
<td>3655</td>
<td>30,6%</td>
</tr>
<tr>
<td>Unknown</td>
<td>1063</td>
<td>8,9%</td>
</tr>
<tr>
<td>Total</td>
<td>11963</td>
<td>100%</td>
</tr>
</tbody>
</table>

* % per column
** % per row of All

### Year of 1\(^{\text{st}}\) Registration & EES

<table>
<thead>
<tr>
<th>Year of 1(^{\text{st}}) Reg.</th>
<th>EES</th>
<th>No / Unknown</th>
<th>Yes</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td>16-50 Km/h</td>
<td>3760</td>
<td>99,8%</td>
<td>9</td>
<td>0,2%</td>
</tr>
<tr>
<td>&gt; 50 Km/h</td>
<td>3294</td>
<td>99,4%</td>
<td>19</td>
<td>0,6%</td>
</tr>
<tr>
<td>&lt; 16 Km/h</td>
<td>153</td>
<td>93,9%</td>
<td>10</td>
<td>6,1%</td>
</tr>
</tbody>
</table>

Sub Total of <2000

|                                 | 7207    | 99,5%        | 38  | 0,5%| 7245 | 100% |

|                                 | 2143    | 99,9%        | 3   | 0,1%| 2146 | 100% |
|                                 | 1441    | 99,7%        | 5   | 0,3%| 1446 | 100% |
|                                 | 61      | 96,8%        | 2   | 3,2%| 63   | 100% |

Sub Total of 2000+

|                                 | 3645    | 99,7%        | 10  | 0,3%| 3655 | 100% |

|                                 | 568     | 100,0%       | 0   | 0,0%| 568  | 100% |
|                                 | 452     | 100,0%       | 0   | 0,0%| 452  | 100% |
|                                 | 43      | 100,0%       | 0   | 0,0%| 43   | 100% |

Sub Total of "Unknown"

|                                 | 1063    | 100,0%       | 0   | 0,0%| 1063 | 100% |

Total

|                                 | 11915   | 99,6%        | 48  | 0,4%| 11963| 100% |

### Case Selection:
- 1\(^{\text{st}}\) collision
- only cars
- frontal impacts (PDOF=11,12,1)
- EES<>"unknown"
**Fuel leakage & cars caught fire after side impact in GIDAS**

<table>
<thead>
<tr>
<th>Year of 1st registration</th>
<th>All</th>
<th>FL + Caught Fire</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>% *</td>
</tr>
<tr>
<td>&lt;2000</td>
<td>2870</td>
<td>59,1%</td>
</tr>
<tr>
<td>2000+</td>
<td>1590</td>
<td>32,7%</td>
</tr>
<tr>
<td>Unknown</td>
<td>400</td>
<td>8,2%</td>
</tr>
<tr>
<td>Total</td>
<td>4860</td>
<td>100%</td>
</tr>
</tbody>
</table>

* % per column  ** % per row of All

### Case Selection:
- 1st collision
- only cars
- side impacts (PDOF=2,3,4&8,9,10)
- EES<>”unknown”

<table>
<thead>
<tr>
<th>Year of 1st Registration &amp; EES</th>
<th>Cars with fuel leakage + Cars caught fire</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No / Unknown</td>
</tr>
<tr>
<td>Year of 1st Reg.</td>
<td>EES</td>
</tr>
<tr>
<td>&lt;2000</td>
<td>&lt; 16 Km/h</td>
</tr>
<tr>
<td></td>
<td>16-50 Km/h</td>
</tr>
<tr>
<td></td>
<td>&gt; 50 Km/h</td>
</tr>
<tr>
<td>Sub Total of &lt;2000</td>
<td></td>
</tr>
<tr>
<td>2000+</td>
<td>&lt; 16 Km/h</td>
</tr>
<tr>
<td></td>
<td>16-50 Km/h</td>
</tr>
<tr>
<td></td>
<td>&gt; 50 Km/h</td>
</tr>
<tr>
<td>Sub Total of 2000+</td>
<td></td>
</tr>
<tr>
<td>Unknown</td>
<td>&lt; 16 Km/h</td>
</tr>
<tr>
<td></td>
<td>16-50 Km/h</td>
</tr>
<tr>
<td></td>
<td>&gt; 50 Km/h</td>
</tr>
<tr>
<td>Sub Total of &quot;Unknown&quot;</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
</tr>
</tbody>
</table>
Back-Up
### Details of fuel leakage & fire magnitude after frontal impact in GIDAS

**Case Selection:**
- 1st collision
- only cars
- frontal impacts (PDOF=11,12,1)
- EES<>“unknown”

#### Year of 1st registration

<table>
<thead>
<tr>
<th>Year of 1st registration</th>
<th>All</th>
<th>Fuel Leakage (FL)</th>
<th>FL + Caught Fire</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>% *</td>
<td>n</td>
</tr>
<tr>
<td>&lt;2000</td>
<td>7245</td>
<td>60,6%</td>
<td>400</td>
</tr>
<tr>
<td>2000+</td>
<td>3655</td>
<td>30,6%</td>
<td>102</td>
</tr>
<tr>
<td>Unknown</td>
<td>1063</td>
<td>8,9%</td>
<td>61</td>
</tr>
<tr>
<td>Total</td>
<td>11963</td>
<td>100%</td>
<td>563</td>
</tr>
</tbody>
</table>

* % per column  
** % per row of All

#### Fuel Leakage (FL) after frontal impact

<table>
<thead>
<tr>
<th>Year of first registration</th>
<th>&lt;2000</th>
<th>2000+</th>
<th>Unknown</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td>Yes, nfs</td>
<td>171</td>
<td>2,4%</td>
<td>42</td>
<td>1,1%</td>
</tr>
<tr>
<td>Fuel Tank</td>
<td>13</td>
<td>0,2%</td>
<td>2</td>
<td>0,1%</td>
</tr>
<tr>
<td>Fuel Lines (Engine Comp.)</td>
<td>204</td>
<td>2,8%</td>
<td>55</td>
<td>1,5%</td>
</tr>
<tr>
<td>Fuel Lines (not EngComp.)</td>
<td>9</td>
<td>0,1%</td>
<td>3</td>
<td>0,1%</td>
</tr>
<tr>
<td>Other</td>
<td>3</td>
<td>0,0%</td>
<td>0</td>
<td>0,0%</td>
</tr>
<tr>
<td>Sub Total</td>
<td>400</td>
<td>5,5%</td>
<td>102</td>
<td>2,8%</td>
</tr>
<tr>
<td>Total</td>
<td>7245</td>
<td>61%</td>
<td>3655</td>
<td>30%</td>
</tr>
</tbody>
</table>

#### Fuel Leakage & cars caught fire after frontal impact

<table>
<thead>
<tr>
<th>Year of first registration</th>
<th>&lt;2000</th>
<th>2000+</th>
<th>Unknown</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td>Engine Compartment</td>
<td>16</td>
<td>0,2%</td>
<td>4</td>
<td>0,1%</td>
</tr>
<tr>
<td>Engine &amp; Passenger Comp.</td>
<td>3</td>
<td>0,0%</td>
<td>2</td>
<td>0,1%</td>
</tr>
<tr>
<td>Total Vehicle</td>
<td>19</td>
<td>0,3%</td>
<td>4</td>
<td>0,1%</td>
</tr>
<tr>
<td>Sub Total</td>
<td>38</td>
<td>0,5%</td>
<td>10</td>
<td>0,3%</td>
</tr>
<tr>
<td>Total</td>
<td>7245</td>
<td>61%</td>
<td>3655</td>
<td>30%</td>
</tr>
</tbody>
</table>
### Cars with Front Impacts in GIDAS Split by Speed Range

<table>
<thead>
<tr>
<th>EES by Frontal Impact (VDI1=11,12,1)</th>
<th>Total</th>
<th>Fuel Leakage (FL)</th>
<th>FL+Fire</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
<td>n</td>
</tr>
<tr>
<td>&lt; 16 Km/h</td>
<td>6483</td>
<td>54,2%</td>
<td>113</td>
</tr>
<tr>
<td>16-50 Km/h</td>
<td>5211</td>
<td>43,6%</td>
<td>360</td>
</tr>
<tr>
<td>&gt; 50 Km/h</td>
<td>269</td>
<td>2,2%</td>
<td>90</td>
</tr>
<tr>
<td>Total</td>
<td>11963</td>
<td>100%</td>
<td>563</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fuel Leakage (FL) after frontal impact</th>
<th>&lt; 16 Km/h</th>
<th>16-50 Km/h</th>
<th>&gt; 50 Km/h</th>
<th>All Speeds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td>Yes, nfs</td>
<td>47</td>
<td>0,6%</td>
<td>151</td>
<td>4,1%</td>
</tr>
<tr>
<td>Tank</td>
<td>6</td>
<td>0,1%</td>
<td>12</td>
<td>0,3%</td>
</tr>
<tr>
<td>Fuel Lines (Engine Comp.)</td>
<td>56</td>
<td>0,8%</td>
<td>187</td>
<td>5,1%</td>
</tr>
<tr>
<td>Fuel Lines (not EComp.)</td>
<td>3</td>
<td>0,0%</td>
<td>8</td>
<td>0,2%</td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
<td>0,0%</td>
<td>2</td>
<td>0,1%</td>
</tr>
<tr>
<td>Sub Total</td>
<td>113</td>
<td>1,6%</td>
<td>360</td>
<td>9,8%</td>
</tr>
<tr>
<td>Total</td>
<td>7245</td>
<td>61%</td>
<td>3655</td>
<td>30%</td>
</tr>
</tbody>
</table>

### Fuel Leakage & cars caught fire after frontal impact

<table>
<thead>
<tr>
<th>Fuel Leakage &amp; cars caught fire after frontal impact</th>
<th>&lt; 16 Km/h</th>
<th>16-50 Km/h</th>
<th>&gt; 50 Km/h</th>
<th>All Speeds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td>Engine Compartment</td>
<td>4</td>
<td>0,1%</td>
<td>12</td>
<td>0,3%</td>
</tr>
<tr>
<td>Engine &amp; Occupant Comp.</td>
<td>1</td>
<td>0,0%</td>
<td>4</td>
<td>0,1%</td>
</tr>
<tr>
<td>Entire Vehicle</td>
<td>7</td>
<td>0,1%</td>
<td>8</td>
<td>0,2%</td>
</tr>
<tr>
<td>Sub Total</td>
<td>12</td>
<td>0,2%</td>
<td>24</td>
<td>0,7%</td>
</tr>
<tr>
<td>Total</td>
<td>7245</td>
<td>61%</td>
<td>3655</td>
<td>30%</td>
</tr>
</tbody>
</table>
### Documented traffic accidents

**GIDAS – Effective 01.07.2012**

<table>
<thead>
<tr>
<th>Category</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicles</td>
<td>40,038 vehicles</td>
</tr>
<tr>
<td>Car occupants</td>
<td>55,750 persons</td>
</tr>
<tr>
<td>Injured persons</td>
<td>29,697 injured persons</td>
</tr>
<tr>
<td>Reconstructions</td>
<td>40,038 reconstructions</td>
</tr>
<tr>
<td>Passenger cars</td>
<td>26,449 passenger cars</td>
</tr>
<tr>
<td>Car occupants</td>
<td>37,830 car occupants</td>
</tr>
<tr>
<td>Single injuries</td>
<td>76,736 single injuries</td>
</tr>
<tr>
<td>Reconstruction events</td>
<td>89,838 reconstruction events</td>
</tr>
<tr>
<td>Trucks</td>
<td>2,618 trucks</td>
</tr>
<tr>
<td>Truck/bus tram occupants</td>
<td>4,589 truck/bus tram occupants</td>
</tr>
<tr>
<td>Slightly injured persons</td>
<td>21,665 slightly injured persons</td>
</tr>
<tr>
<td>Vehicle-to-vehicle collisions</td>
<td>34,747 vehicle-to-vehicle collisions</td>
</tr>
<tr>
<td>Busses &amp; trams</td>
<td>862 busses &amp; trams</td>
</tr>
<tr>
<td>Pedestrians</td>
<td>3,001 pedestrians</td>
</tr>
<tr>
<td>Seriously injured persons</td>
<td>7,414 seriously injured persons</td>
</tr>
<tr>
<td>Vehicle-to-object collisions</td>
<td>11,444 vehicle-to-object collisions</td>
</tr>
<tr>
<td>Two-wheelers</td>
<td>9,989 two-wheelers</td>
</tr>
<tr>
<td>Cyclists</td>
<td>10,330 cyclists</td>
</tr>
<tr>
<td>Fatally injured persons</td>
<td>618 fatally injured persons</td>
</tr>
</tbody>
</table>
Supporting Data for the Probability Vehicle Occupants are Unable to Leave the Vehicle Post-Collision
Question: What is the probability that occupants are unable to leave the vehicle in the event of a crash


The authors conducted a review of accident records for a township located in New York state. They reported that 38 of 14,450 motor vehicle collisions (the total number reported during the time period of study) required some extrication (0.3%, 0.0026). This number would apply to the overall frequency of entrapment in collisions of any severity. The authors also reported that 38 of 2,095 collisions which involved personal injury required extrication (2%, 0.018). Because this subset of collisions (14% of the total) involved injury, they would be more characteristic of mid-to high severity collisions. Note that the 38 extrications required when there was injury is the same number of extrications required among all collisions, meaning that the number of extrications required when there is no personal injury was 0. Finally, the authors reported that 38 of 198 motor vehicle crashes to which a fire department responded, suggesting the most serious type of crash, required some extrication (20% or 0.19). It is probably reasonable to suggest that this number would be most characteristic of high severity collisions.

US State of Tennessee, Department of Safety, data for 2007
www.tn.gov/safety/stats/CrashData/default.shtml
2007 total collisions= 172,130
2007 – total number of individuals trapped in motor vehicle accidents – 3,448 (whether successfully extricated or not)
This is the total number of individuals, not the number of collisions, involving extrication. If we divide this by the typical number of passengers per vehicle in the US (approximately 1.5), we get ~2300 collisions which involved/required extrication. The ratio, 2,300/172,130 yields an extrication frequency of 1.3% or 0.013. Note that this number pertains to all crashes, regardless of severity.

US State of Nebraska, State Fire Marshall, data for 2000
Number of vehicle accidents with injuries which involved a response = 2,662
Cases requiring extrication of victim(s) from vehicle = 26
This is equivalent to 0.01 or 1% of vehicle collisions which involved injuries severe enough to require emergency services involvement.

City of Minneapolis, MN
http://uclue.com/?xq=1812
Motor vehicle accidents with injuries = 679
Cases requiring extrication of victim(s) from vehicle = 22
Overall frequency: 3% (0.032)
City of Midland, MI
Accidents with injuries where EMS/fire department is called in = 135
Cases requiring occupant extrication = 5
Overall frequency: 4% (0.037)

Data for Orange County FL
(www.orangecountyfl.net/.../Orange%20Spiel%20Feb-Mar%202011.pdf)
It was reported that for 1 day (Sept 24, 2010) fire and rescue services responded to 27 vehicle accidents of which 1 involved extrication 4% (0.037). However, the same size is quite small.

However, it was also reported for Orange County (http://uclue.com/?xq=1812):
"for one year, 13,313 traffic accidents, and 531 entrapments". Level of severity was not specified but will be assumed to mean all accident types. This equates to a frequency of 4% (0.04) per accident.

Taken together these data suggest that for all collisions combined (dominated by low speed collisions, many of which will not involve emergency responders), the risk the occupants are unable to leave the vehicle post-collision is probably less than 1% (based on Funk et al. and data from Tennessee). The smaller datasets (Midland MI, Orange County FL, Minneapolis MN) suggest slightly higher percentages (3-4%) but these do not reflect very low speed collisions where EMS or the fire department are not called. It is more likely that such collisions only involve police services, e.g., for filling out a report for insurance purposes. For collisions involving injuries (consistent with a medium or high severity collision) the risk of needing extrication is probably more on the order of 1-4% (data for Nebraska, Midland MI, Minneapolis MN, and Orange County FL all of which reflect fire department/EMS statistics). For even more serious crashes (i.e., high severity crashes) the risk may be as high as 20% (based primarily on Funk et al.).

Based on an average probability of occupants being unable to leave the vehicle post-collision of 1% (for all crashes), the CRP chose to use a value of 5% for high severity front collisions, 20% for high severity side collisions (which have greater potential for damaging vehicle doors), 0.1% for mid severity front, 5% for mid severity side, and 0.01 % for low severity front and side collisions.
Attachment K

OEM Test Data on Vehicle Operating Temperatures
Percent of Time Exhaust Surface Temperatures are above 600°C and 700°C*

<table>
<thead>
<tr>
<th>Vehicle/ Powertrain Description</th>
<th>50th Percentile Customer</th>
<th>90th Percentile Customer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50th Percentile Customer</td>
<td>90th Percentile Customer</td>
</tr>
<tr>
<td></td>
<td>Percent of Customer Hours</td>
<td>Percent of Customer Hours</td>
</tr>
<tr>
<td>Medium Size Van FWD Turbo Diesel</td>
<td>2.6% 0.0335% 2.5%</td>
<td>4.4% 0.0197% 4.4%</td>
</tr>
<tr>
<td>Small Van FWD Gas Non-Turbo</td>
<td>3.9% 1.8% 2.1%</td>
<td>5.3% 2.4% 2.9%</td>
</tr>
<tr>
<td>Small Cross Utility FWD Gas Turbo Direct Injection</td>
<td>6.2% 3.1% 3.2%</td>
<td>10.9% 5.7% 5.2%</td>
</tr>
</tbody>
</table>

*Based on Standard Thermal Test Results and Customer Use profile

The results of this analysis incorporated into the SAE CRP FTA Sensitivity Analysis